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Mission Performance Centre

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European Commission

# SENTINEL-2 GLOBAL SURFACE REFLECTANCE LEVEL-2A PRODUCT GENERATED WITH SEN2COR

IGARSS 2019

PACIFICO YOKOHAMA | YOKOHAMA | JAPAN

1 AUGUST 2019

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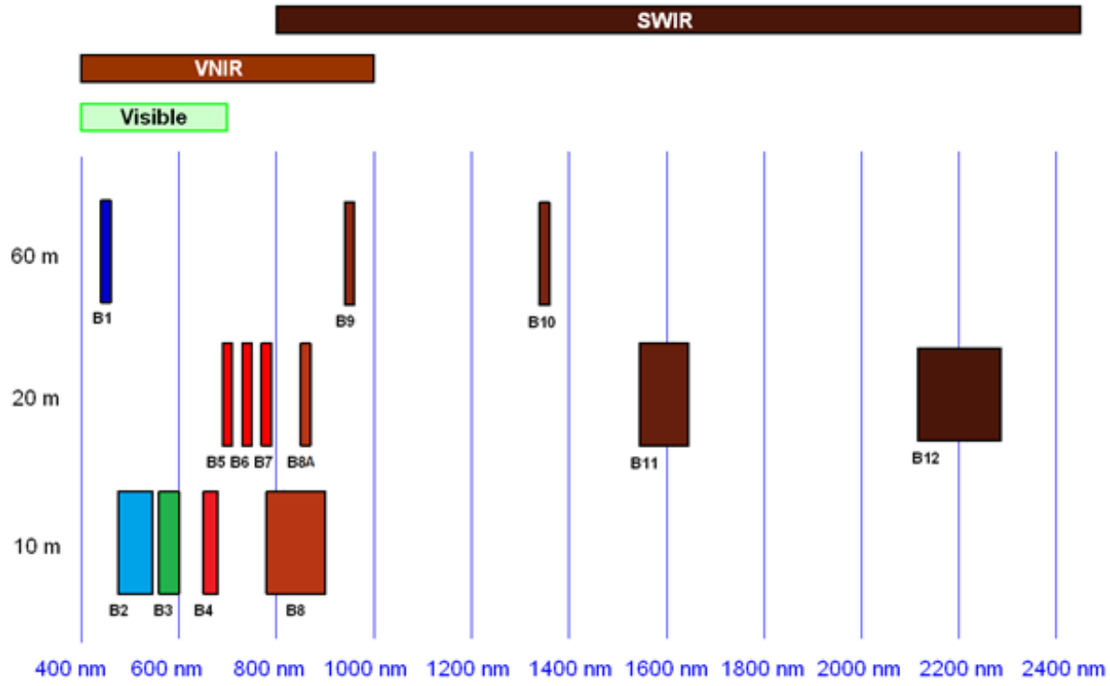
# Table of Contents

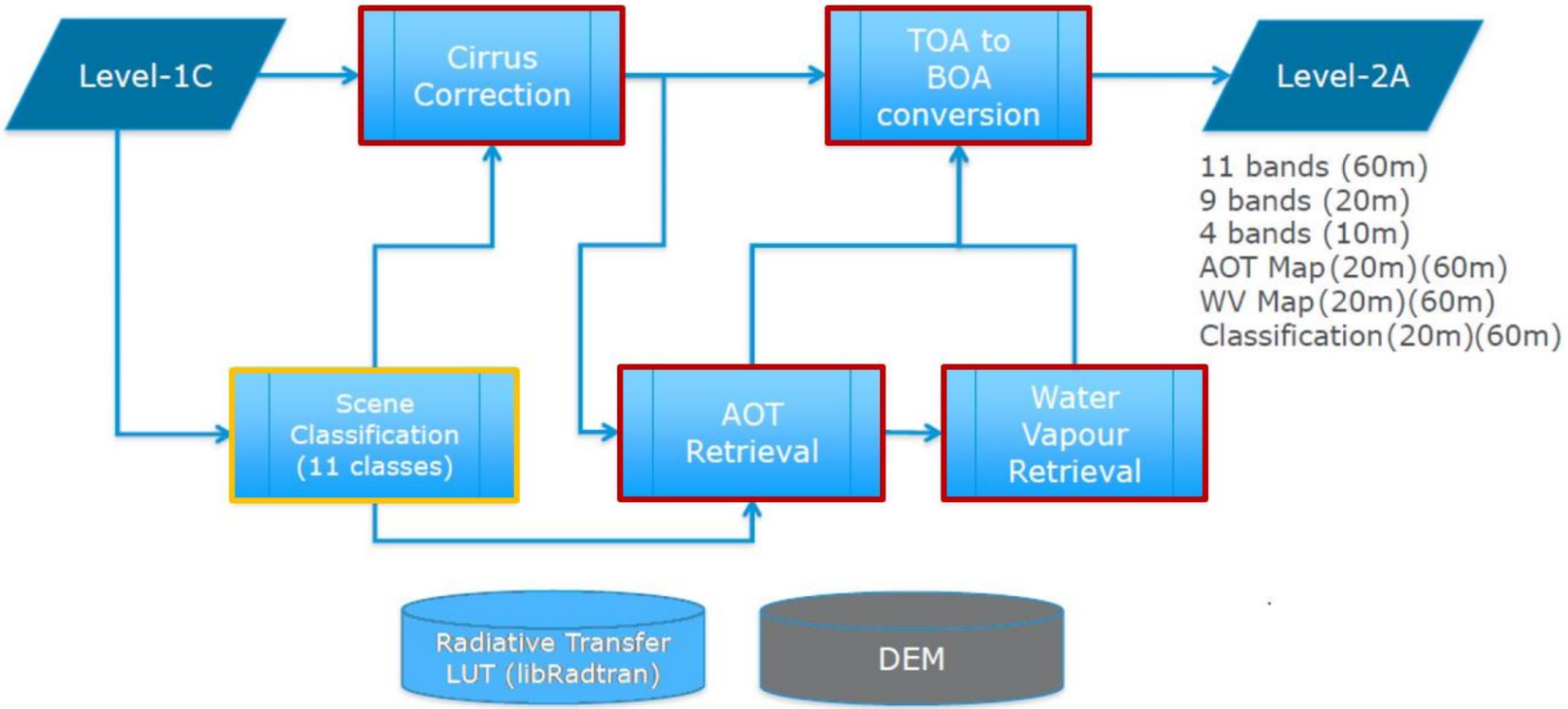
# SENTINEL-2 MISSION

- Optical mission for land and coastal region monitoring and emergency services
- Constellation of 2 satellites S2A and S2B (June 2015 & Mars 2017)
- Polar, Sun-synchronous orbit:
- Swath of 290km
- Global coverage with 5 days or less revisit period with both satellites



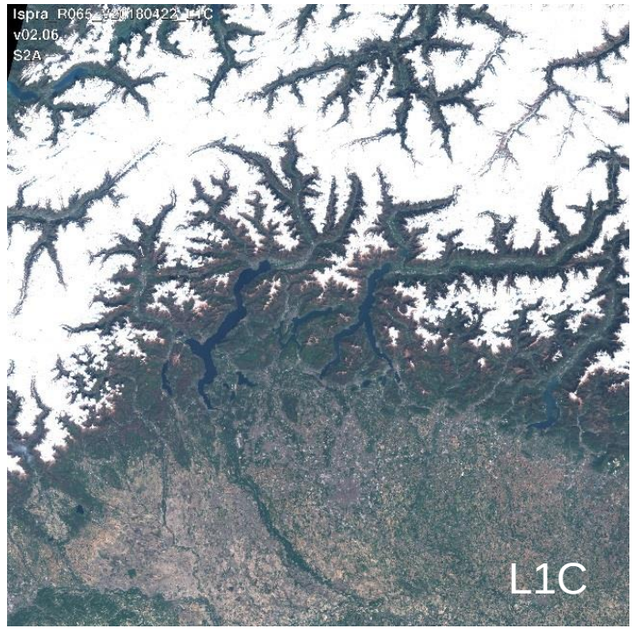

13 spectral bands
spatial resolution
10 m, 20 m, 60 m.

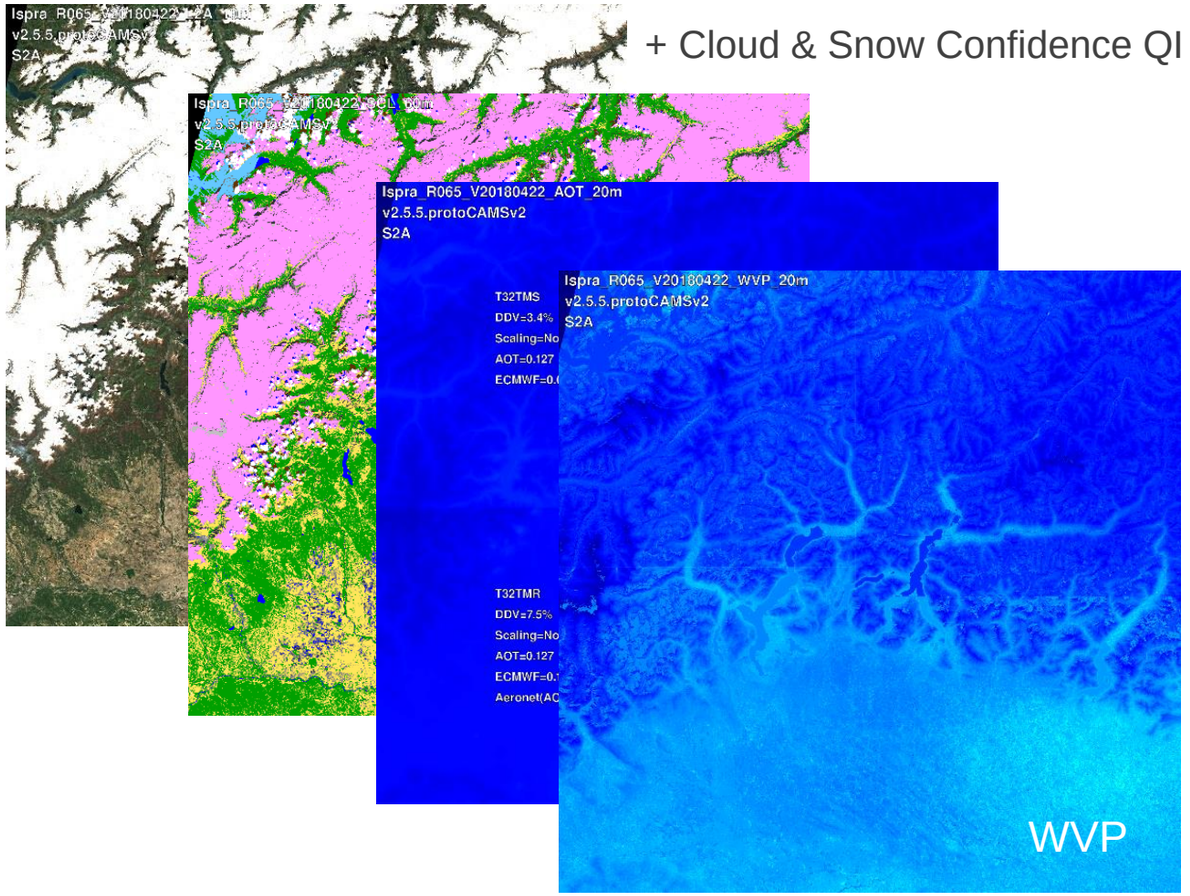
# LEVEL-2A PROCESSING STEPS




- Two main modules : Scene Classification (SCL) and Atmospheric Correction (AC)
- Set of Look-Up Tables (LUTs) generated with libRadtran
- AOT derived at 550nm based on the DDV (Dense Dark Vegetation) algorithm
- WV retrieval based on the Atmospheric Pre-corrected Differential Absorption Algorithm (APDA)

# L2A Processor Outputs

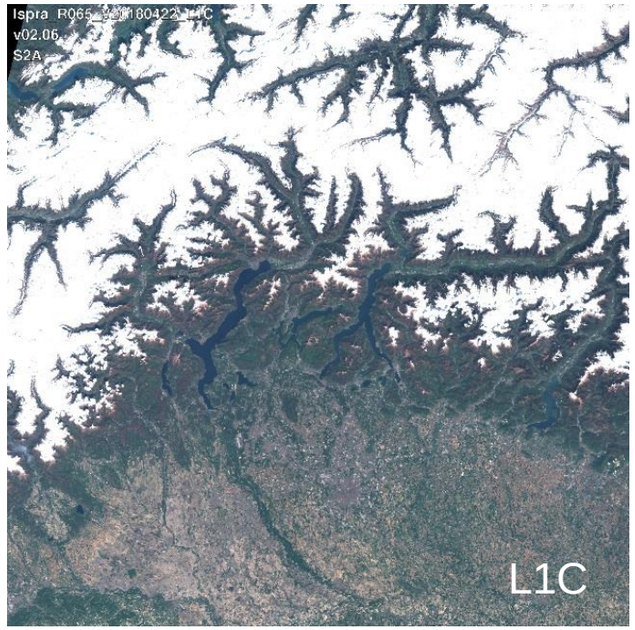


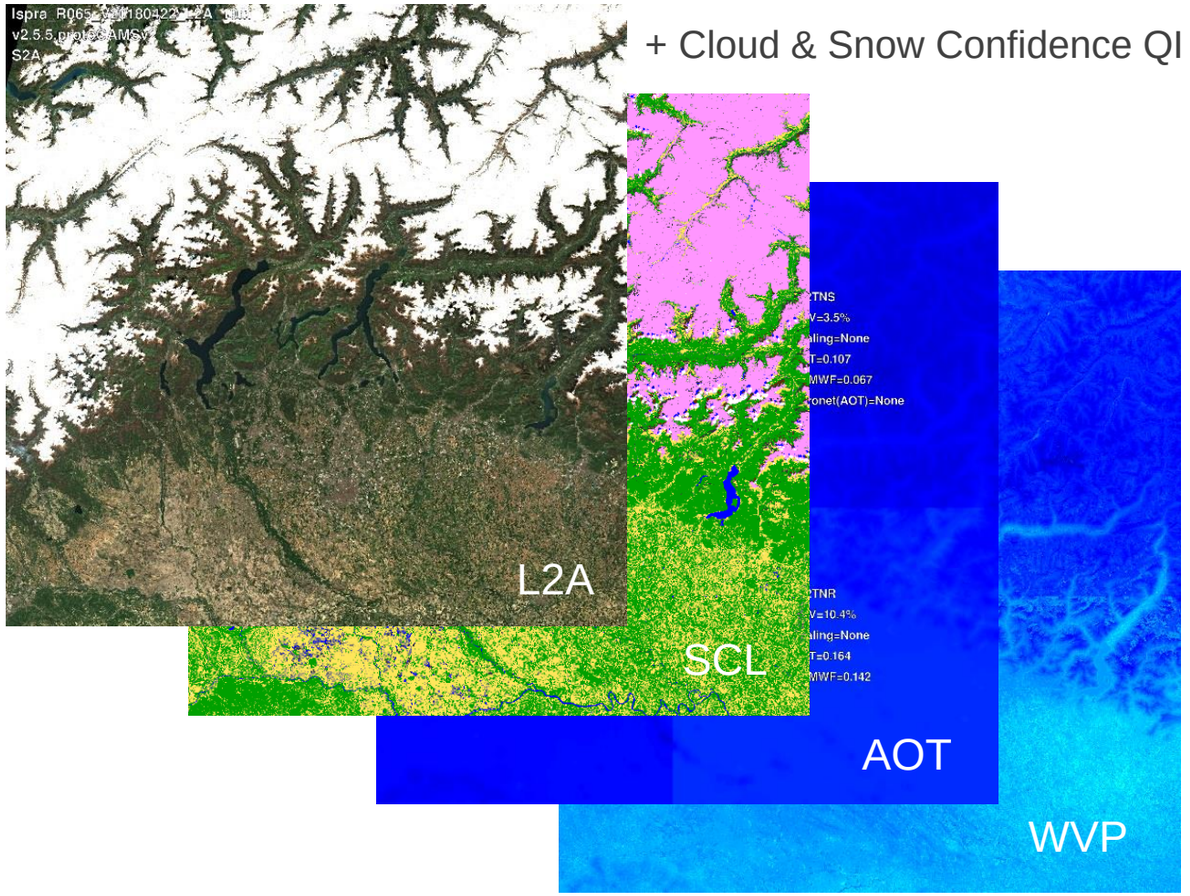




+ Cloud & Snow Confidence QI

Sentinel-2A product
Four tiles
North of Italy
22 April 2018

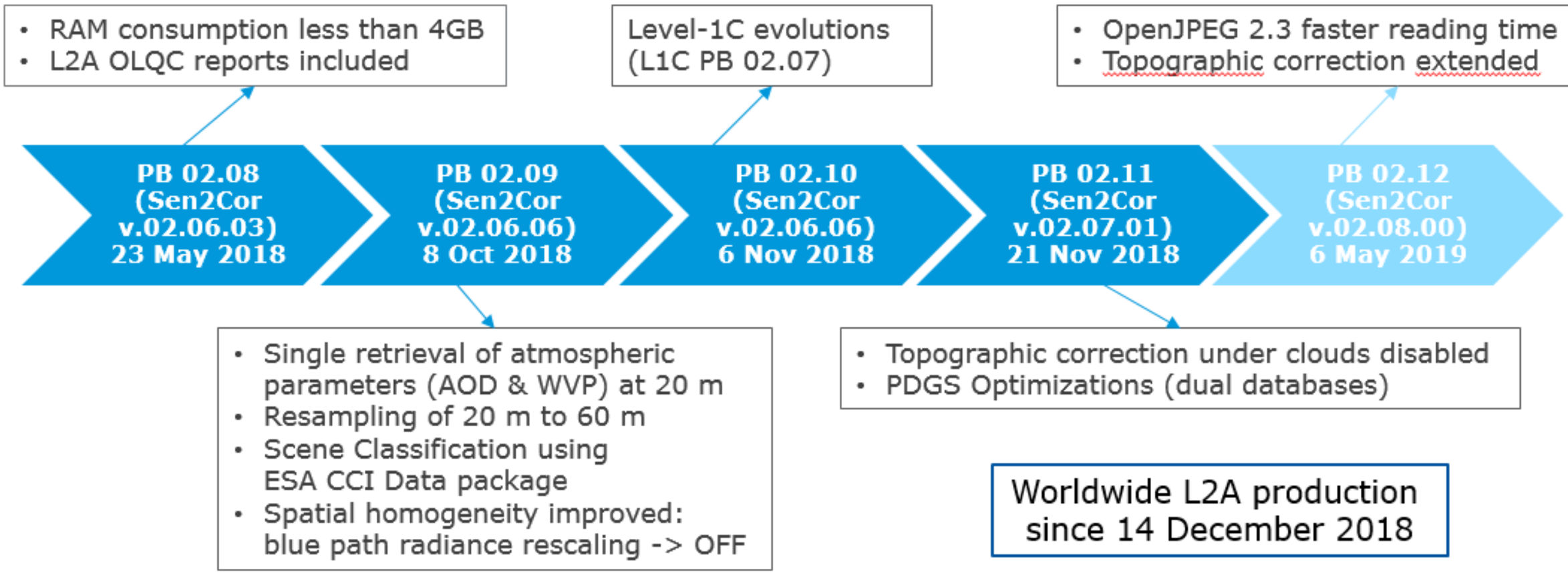
# L2A Processor Outputs




Sentinel-2A product
Four tiles
North of Italy
22 April 2018

# LEVEL-2A PROCESSING BASELINES



# SEN2COR VERSIONS

- **General User's version:**
  - **Version 2.5.5 released on March 19, 2018 (publicly available)**
    **(For L1C with PSD older than 14.2 and not reprocessed by ESA)**
  - **Version 2.8 released on May 10, 2019 (publicly available)**

- **S2 PDGS versions:**
  - **Version 2.8.0 in operations since May 9, 2019**

Download site: http://step.esa.int/main/third-party-plugins-2/sen2cor/

Data Quality Reports: https://sentinels.copernicus.eu/web/sentinel/data-product-quality-reports

# L2A Validation Results: Cloud Screening and Scene Classification

## Accuracy assessment for SCL product with 11 classes, and for clear pixels vs clouds separation

| Site | OA | OA clear pixels | OA clouds | Pixel validated |
|---|---|---|---|---|
| Antarctic | 94.7 | 96.8 | 98.8 | 527803 |
| Barrax (Spain) -1 | 64.6 | 96.9 | 98.7 | 141546 |
| Barrax (Spain) -2 | 90.5 | 98.7 | 99.5 | 104799 |
| Berlin (Germany) | 93.4 | 96.5 | no clouds | 51964 |
| Casleo (Argentina) | 63.8 | 86.1 | 98.1 | 186238 |
| Dunhuang (China) | 57.3 | 66.2 | no clouds | 105454 |
| Manila (Phillipines) | 82.1 | 90.0 | 91.6 | 106263 |
| Rimrock (USA) | 90.2 | 98.2 | 99.2 | 103394 |
| Yakutsk (Russia) | 69.9 | 93.8 | 92.9 | 177983 |
| Etna Volcano (Italy) | 95.8 | 97.9 | 99.4 | 132340 |
| Kilauea Volc. (Hawaii, U) | 60.4 | 75.4 | 74.2 | 118357 |
| Lagos (Portugal) | 96.8 | 97.3 | no clouds | 69753 |
| Buenos Aires (Argentina) | 91.8 | 97.3 | no clouds | 31841 |
| Tallin (Estonia) | 84.3 | 90.4 | 95.6 | 71773 |
| | | | Total: | 1929508 |
| Average | 81.1 | 91.5 | 94.8 | 137822 |
| Stdev | 14.6 | 9.7 | 7.8 | |

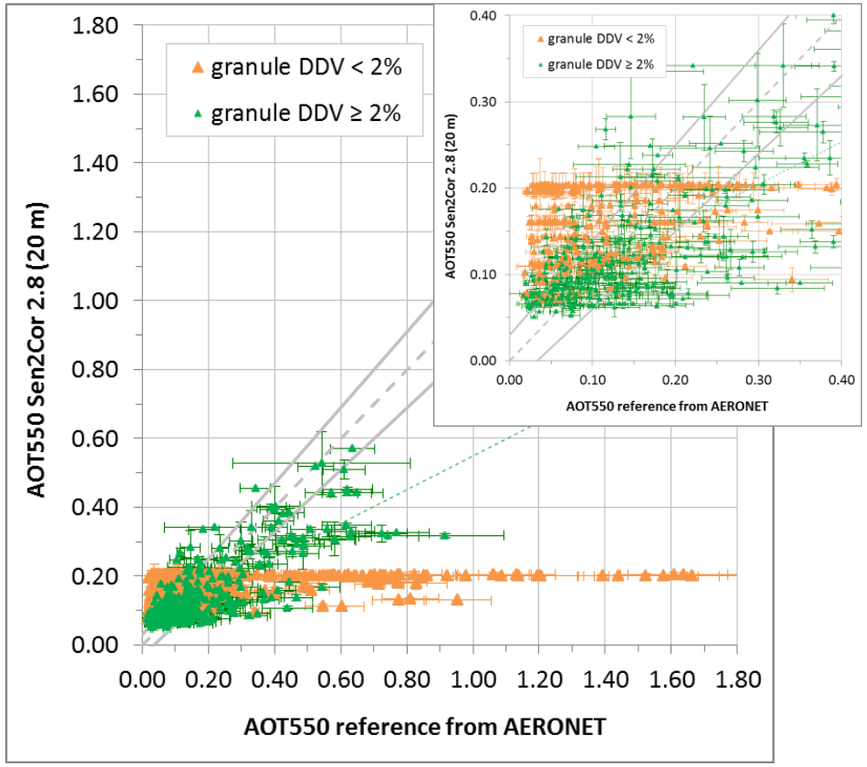
Validation data set with different:

- atmospheric conditions (e.g. cloud cover)
- latitudes (various solar angles and seasons)
- topography (flat, rough and mountainous terrain)
- land cover types (agricultural area, forests, water bodies, arid area, urban area, deserts, permanent ice, and active volcanos).

- The average OA for 14 classification products reached 81.1 ± 14.1%.
- Overall Accuracy (OA) of clear pixels aggregates results for the Sen2Cor classes “vegetation”, “non-vegetated” and “water”.
- OA of clouds aggregates results for Sen2Cor classes “cloud medium probability”, “cloud high probability” and “thin cirrus”.
- **The recognition of clear pixels reached an OA of 91.5% and a consolidated OA for clouds recognition is 94.8%.**

# L2A VALIDATION RESULTS: AOT550 RETRIEVAL PERFORMANCE

Sen2Cor 2.8 public version




| **AOT statistics** **Sen2Cor2.8** | Complete set | DDV subset |
|---|---|---|
| Total no. of products | 702 | 337 |
| Products within specification | 36% | 48% |
| $R^2$ (Coefficient of variation) | 0.21 | 0.63 |
| r (Pearson's correlation coeff.) | 0.45 | 0.80 |
| MD (Median deviation ) | 0.06 | 0.04 |
| MA (Median Accuracy value) | 0.004 | -0.007 |
| MP (Median Precision value) | 0.23 | 0.10 |
| U (Uncertainty) | 0.24 | 0.11 |
| Max $AOT_{550}$ difference | 1.65 | 0.60 |

› **solid lines**: Accuracy requirement $|\Delta AOT550| \leq 0.1*AOT550_{ref}+0.03$

› **Dashed line**: Sen2Cor_output = Reference

› **Green triangles**: Results for **DDV**-algorithm

› **Orange triangles**: **fall-back** processing

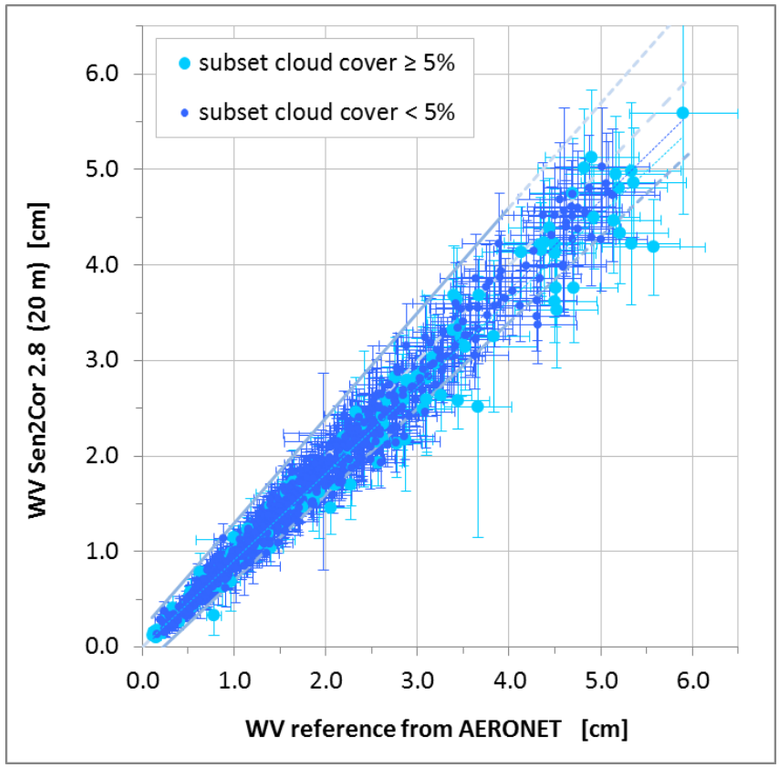
› Linear trend lines for DDV and fall-back

➔ **DDV processing: underestimation of high AOT values and overestimation of low AOT**

➔ **Results for the noDDV granules show the need for releasing a better fall-back solution based on CAMS-AOT data**

# L2A Validation Results: WV retrieval performance

Sen2Cor 2.8 public version




| WV statistics Sen2Cor2.8 | | Complete set |
|---|---|---|
| Total no. of products | | 702 |
| Products within specification | | 94% |
| $R^2$ | (Coefficient of variation) | 0.98 |
| r | (Pearson's correlation coeff.) | 0.99 |
| MD | (Median deviation ) | 0.12 cm |
| MA | (Median Accuracy value) | -0.11 cm |
| MP | (Median Precision value) | 0.19 cm |
| U | (Uncertainty) | 0.24 cm |
| Max $AOT_{550}$ difference | | 1.39 cm |

› **solid lines**: Accuracy requirement |ΔWV| ≤0.1*WVref+0.2

› **Dashed line**: Sen2Cor_output = Reference

› **Blue Circles**: Results for **cloud cover <5%**

› **Cyan circles**: Results for **cloud cover ≥ 5%**

› Linear trend line

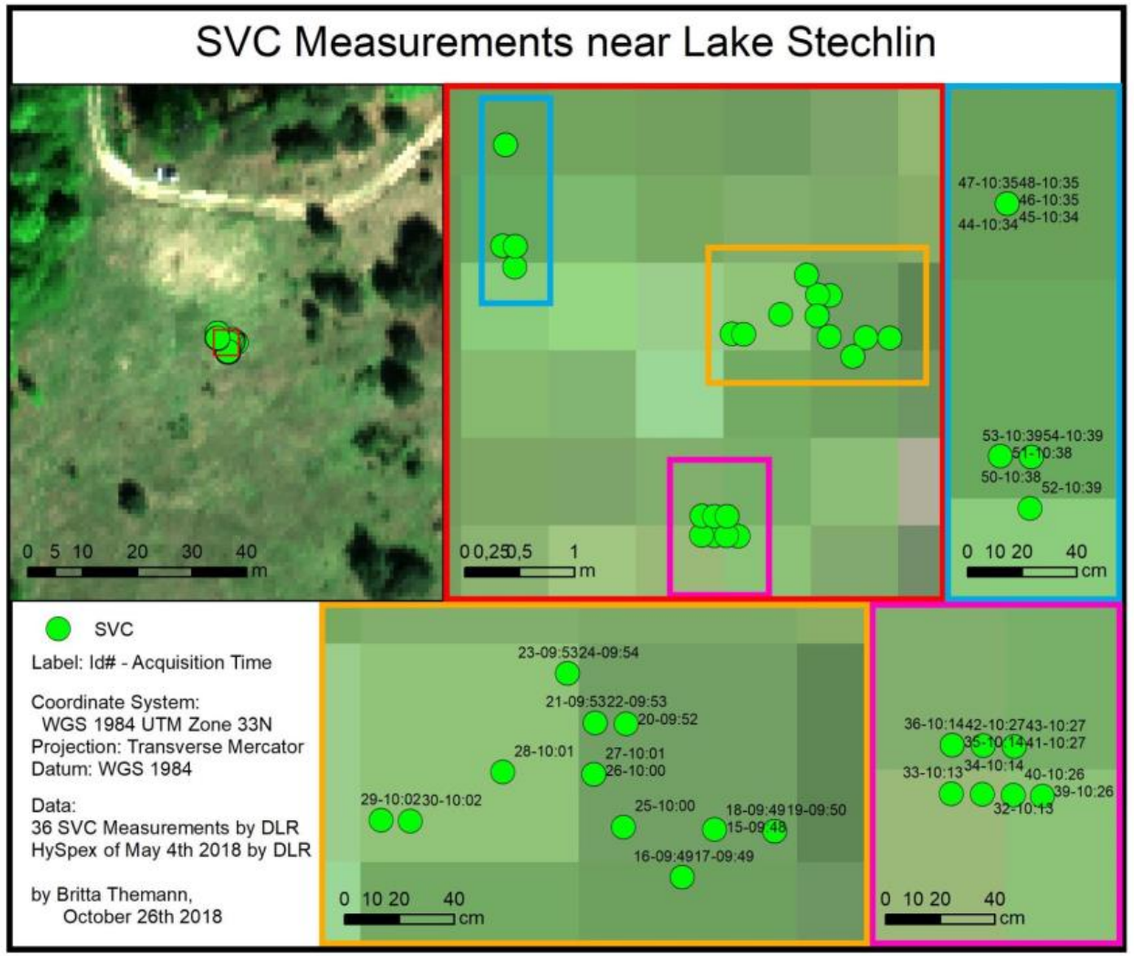
➔ **Very accurate WV retrieval**

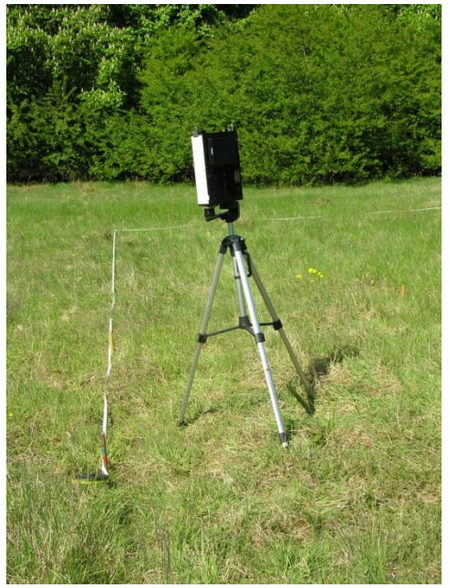
➔ **Trend: light underestimation of WV**

➔ **Larger differences occur for cloudier situations (may be linked to the influence of cloud borders)**

# L2A Validation Results: Surface Reflectance (Campaign Lake Stechlin)

- **Available measurements for Surface Reflectance:**
  - SVC spectrometer (HR-1024i)



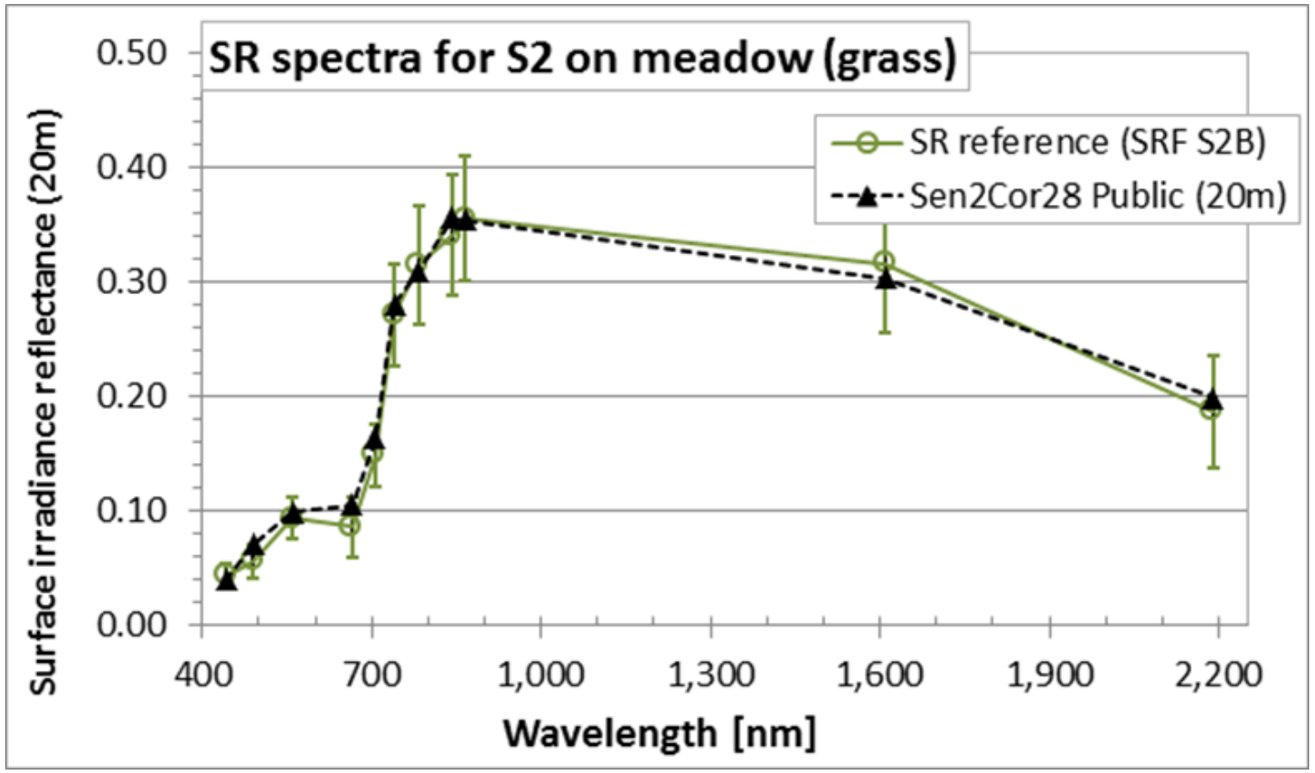



Date : 4th May 2018

- **$AOD_{550nm}$:**
  **Microtops Sunphotometer: 0.07 ±0.04**
- **WV [cm or g.cm-2]:**
  **Microtops ozonometer: 0.59 ±0.12**

# L2A Validation Results: Surface Reflectance (Campaign Lake Stechlin)

**Surface reflectance Reference: Average of SVC measurements on ground for one S2-pixel**




Processor relative to SR reference

| SR (20 m) | RMSD | corr |
|---|---|---|
| Sen2Cor public | 0.022 | 0.973 |

Corr = coefficient of determination

- **Sen2cor 2.8 surface reflectance spectrum agrees well with Surface reflectance Reference**
- **Bands 11, 12 and 5 agree with reference**

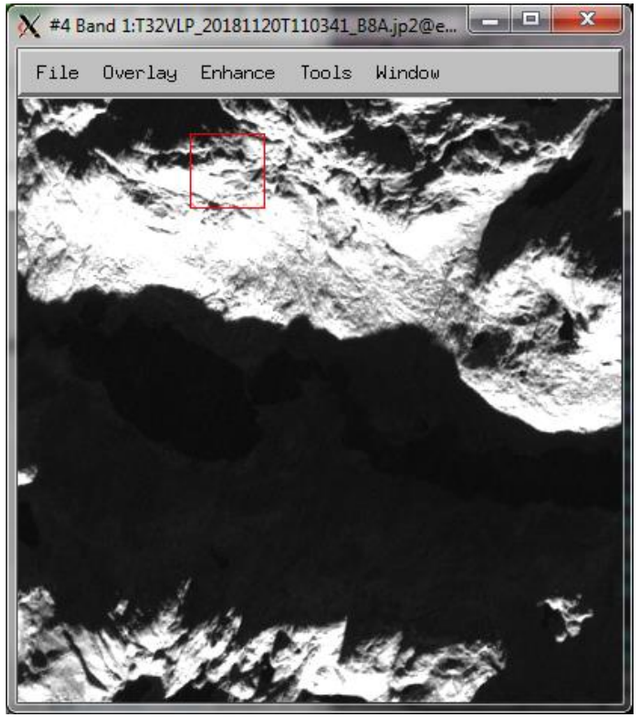

Level 1C product: S2B_MSIL1C_20180504T101029_N0206_R022_T33UUU_20180504T122043.SAFE

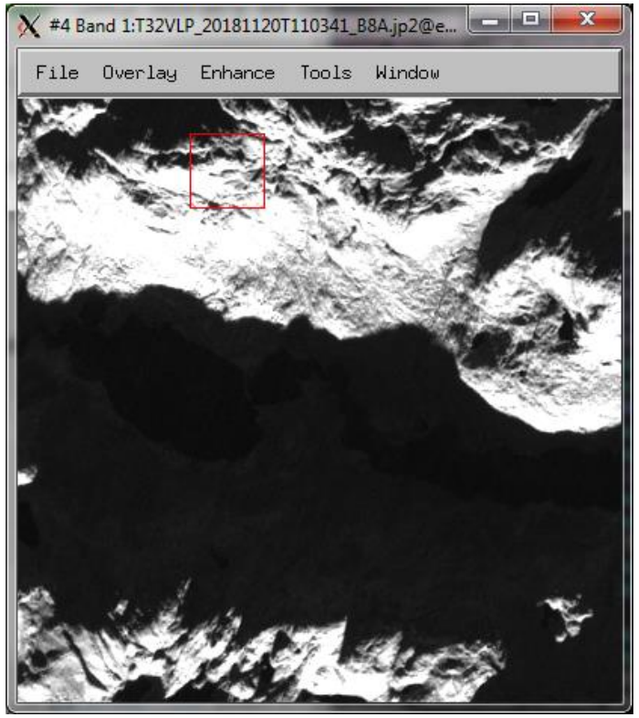
# Evolution of SCL Algorithm: Casted Shadows

## ➔ Casted Shadow Algorithm

- Current version is based on gdaldem –hillshade algorithm limited to sun incidence angle comparison with terrain slope without casted shadow propagation

  → not possible to find a topographic shadow on a flat area (e.g. lakes or plain)



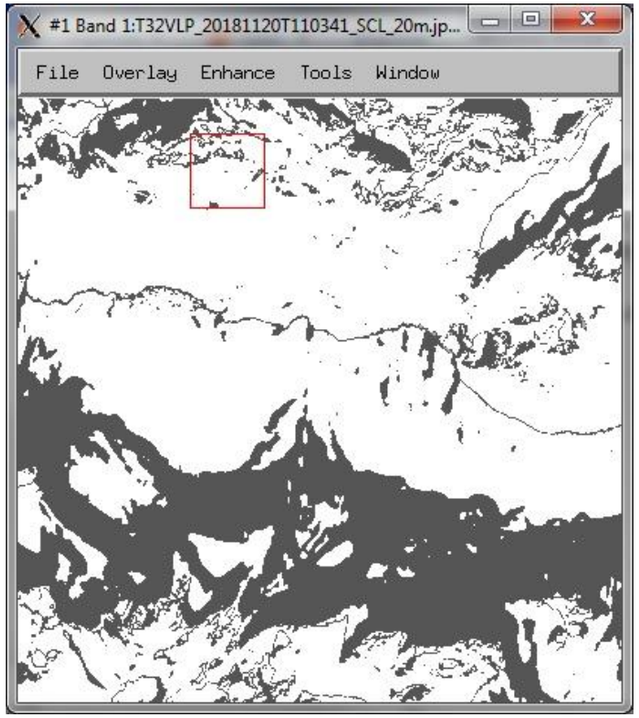
# EVOLUTION OF SCL ALGORITHM: CASTED SHADOWS

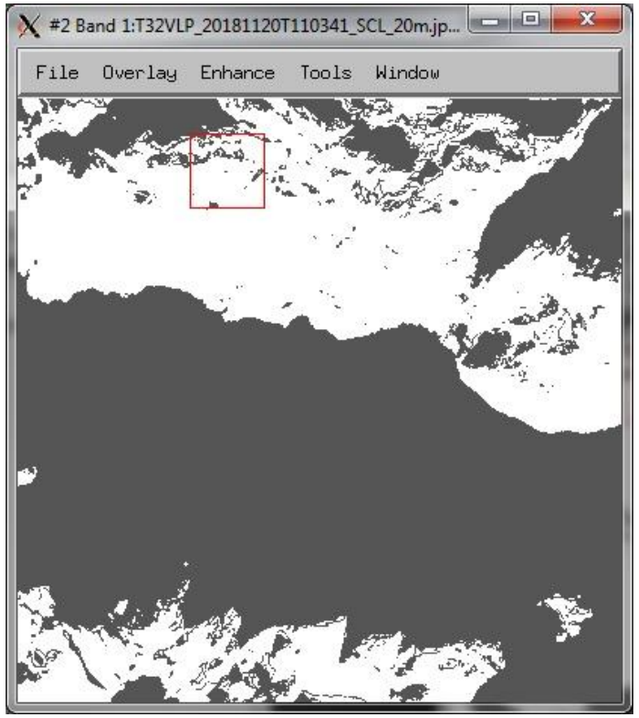
## ➔ Casted Shadow Algorithm

- Plan to use Corripio, J.G. 2002 routines

  (activated only on S2 tiles with particular illumination conditions)

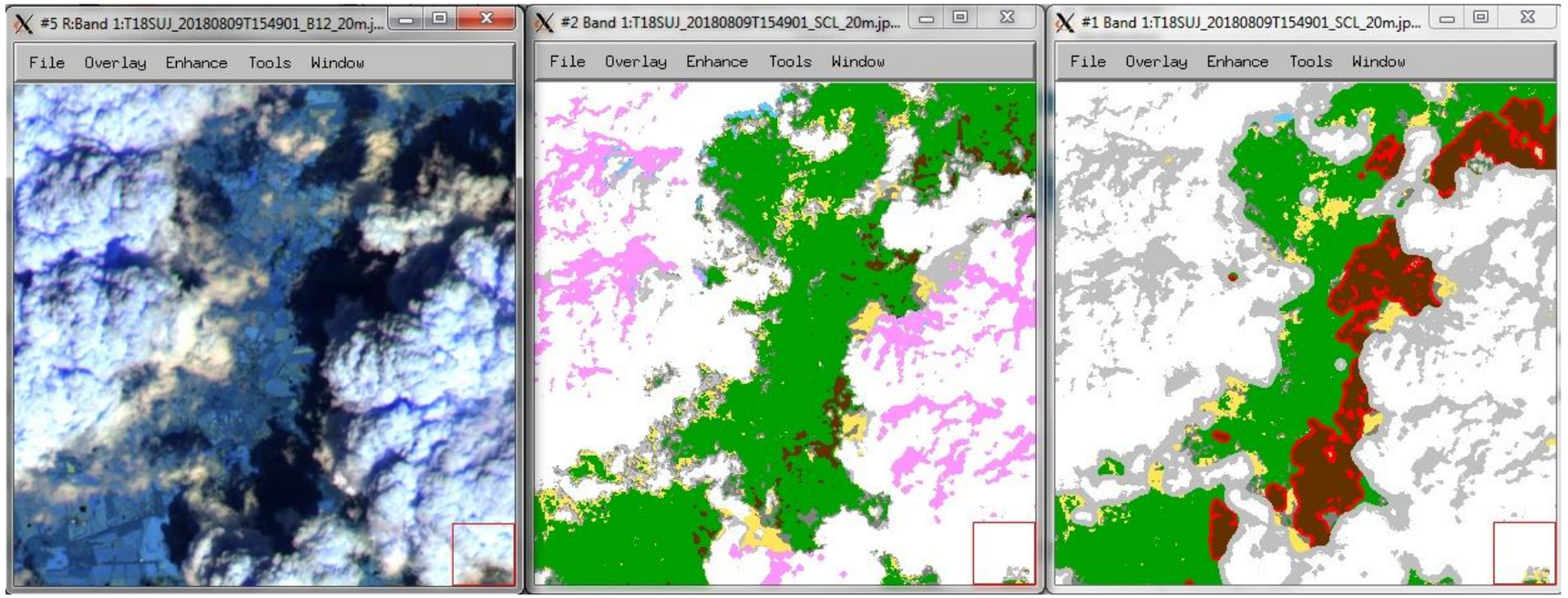
  “Vectorial algebra algorithms for calculating terrain parameters from DEMs and solar radiation modeling in mountainous terrain” January 2003 International Journal of Geographical Information Science 17(1):1-23



# Evolution of SCL Algorithm: False Snow Detection in Clouds

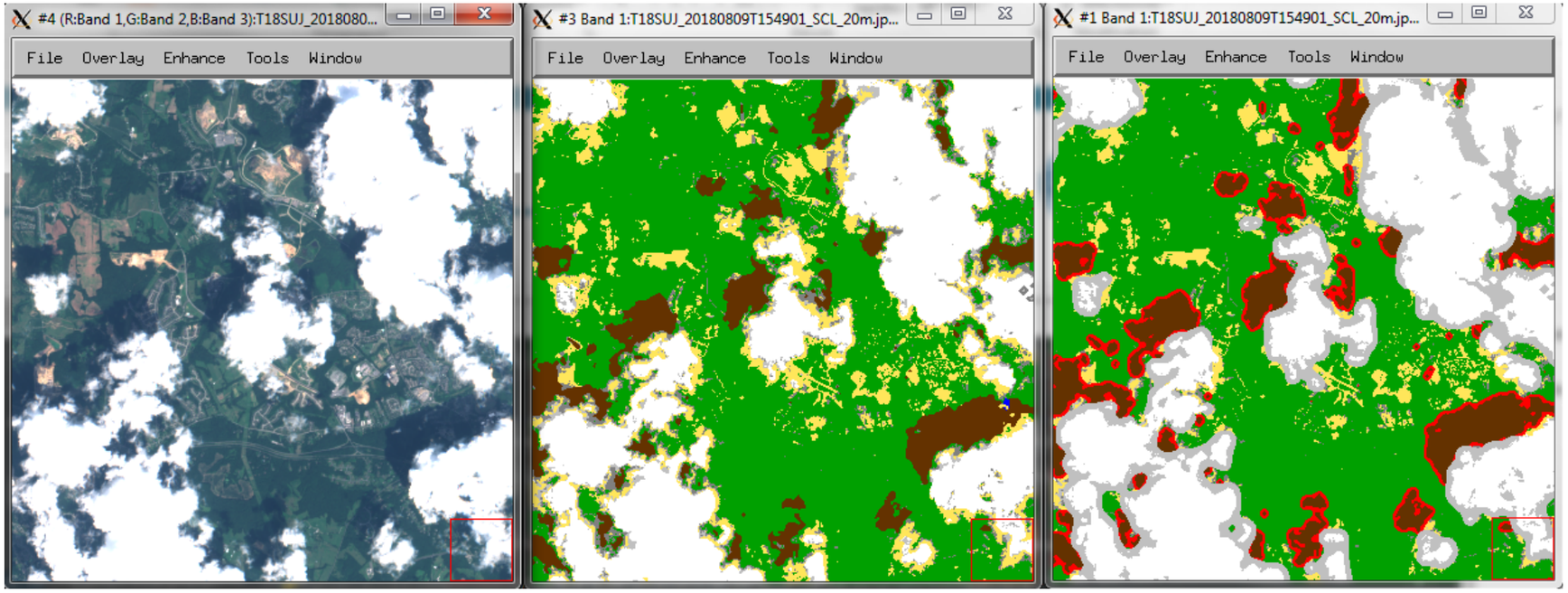
- Limiting false snow detection in clouds
  - Post-processing of ESA CCI 52 Weekly Snow Condition files
    - Aggregation into 12 Monthly Snow Condition files
    - E.g. February Snow Condition file contains information on January, February, March




RGB: B12, B11, B8A | PB.02.12 | Prototype

# EVOLUTION OF SCL ALGORITHM: CLOUD MASK DILATION STRATEGY

- SCL map dilation strategy (on-going)
  - + 80 m cloud mask
  - + 40 m cloud shadow mask
  - Careful dilation to avoid false cloud dilation leading to higher commission error




RGB: B04, B03, B02 PB.02.12 Prototype

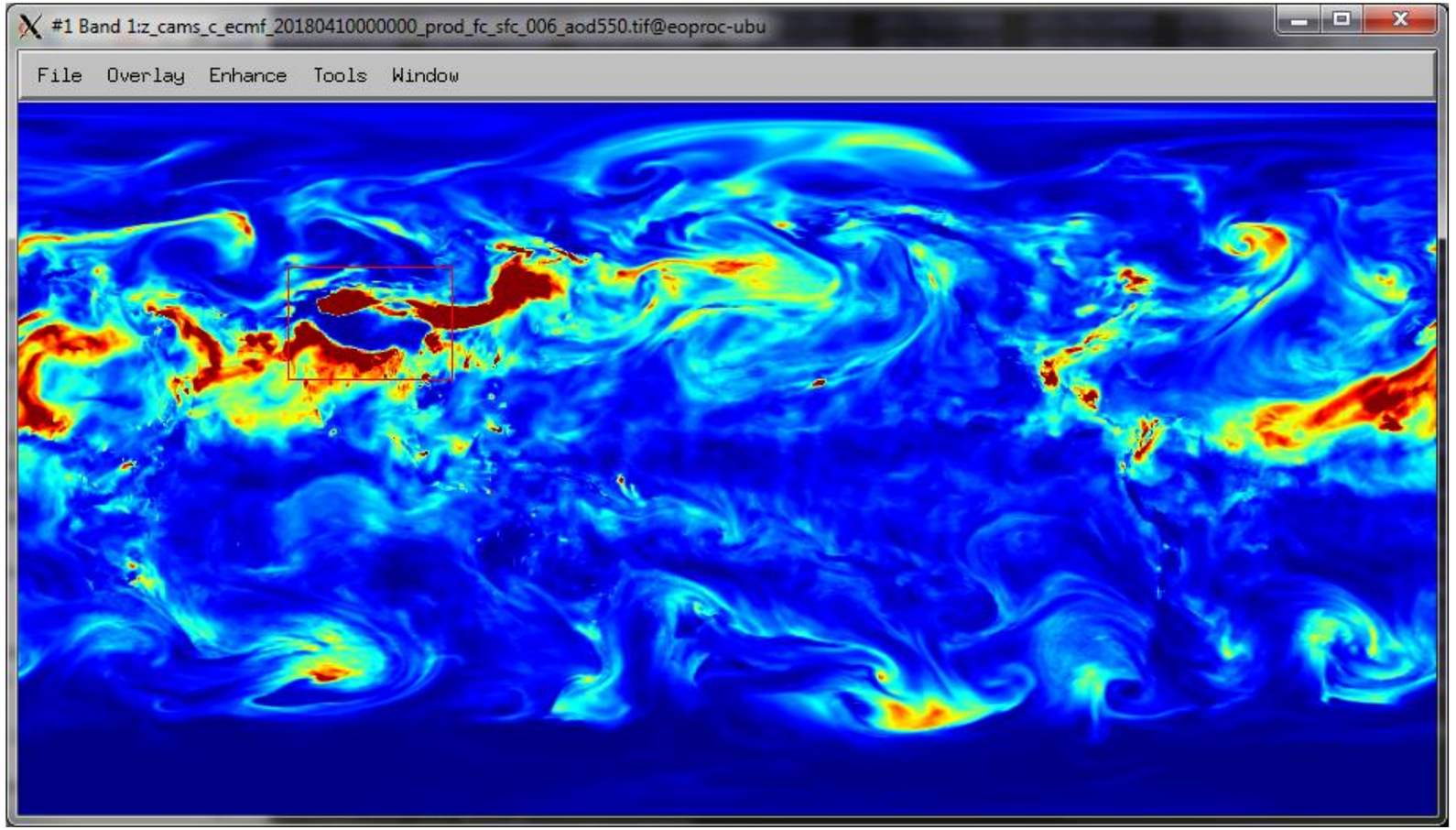
# EVOLUTION OF AC ALGORITHM: ECMWF-CAMS AOD AT 550 NM FALLBACK

- Fall back solution when Dark Dense Vegetation (DDV) pixels are missing in the image.
  - ECMWF-CAMS Total AOD at 550 nm short term forecast (< 12 hours)
  - Data available on Operational FTP with short-term rolling archive (~ 3 days)
  - CAMS data is collected daily
  - CAMS data quality is controlled above L2A calibration test sites.

- Sen2Cor CAMS prototype developed by TPZ F
- First validation performed by DLR on ACIX dataset

Copernicus Atmosphere Monitoring Service (CAMS) website:
https://atmosphere.copernicus.eu/

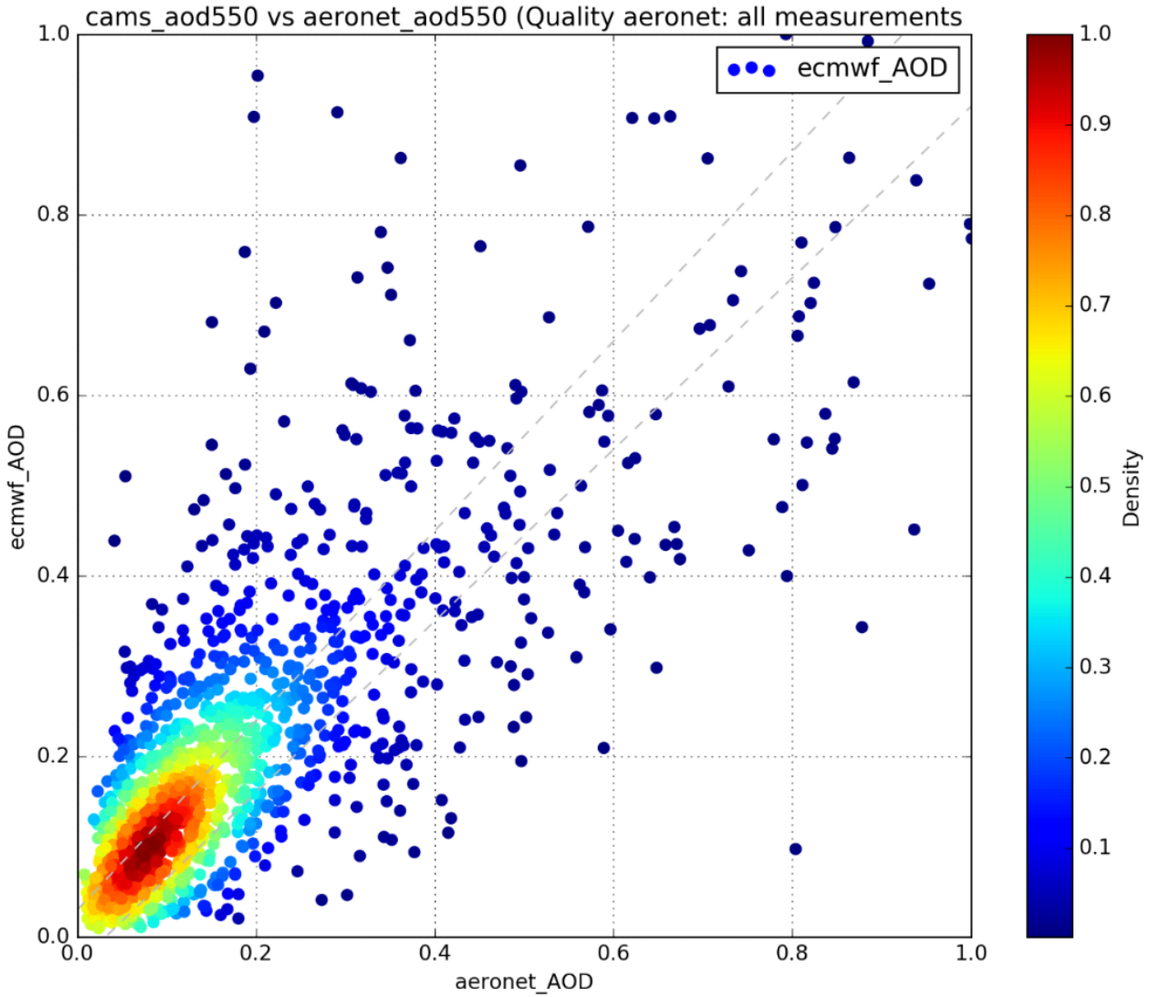
# EVOLUTION OF AC ALGORITHM: ECMWF-CAMS AOD AT 550 NM FALLBACK




Example of CAMS product retrieved from operational FTP

Projection and Resolution: Geographic projection (lat-lon grid) @ 0.4 x 0.4 deg resolution

# EVOLUTION OF AC ALGORITHM: ECMWF-CAMS AOD AT 550 NM FALLBACK




Nsamples: 1442 (over 21 aeronet sites)

Pearson's corr. Coeff
R(all): 0.80

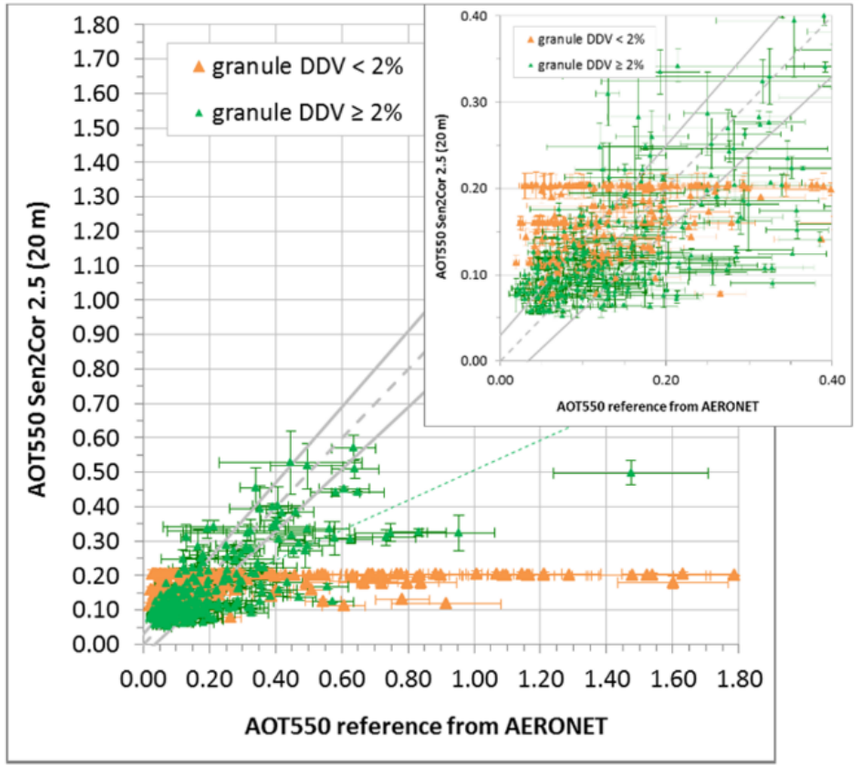
Bias: ~ 0,03
Slope: ~ 1,06

Slight overestimation for
lower aerosol loads < 0.25

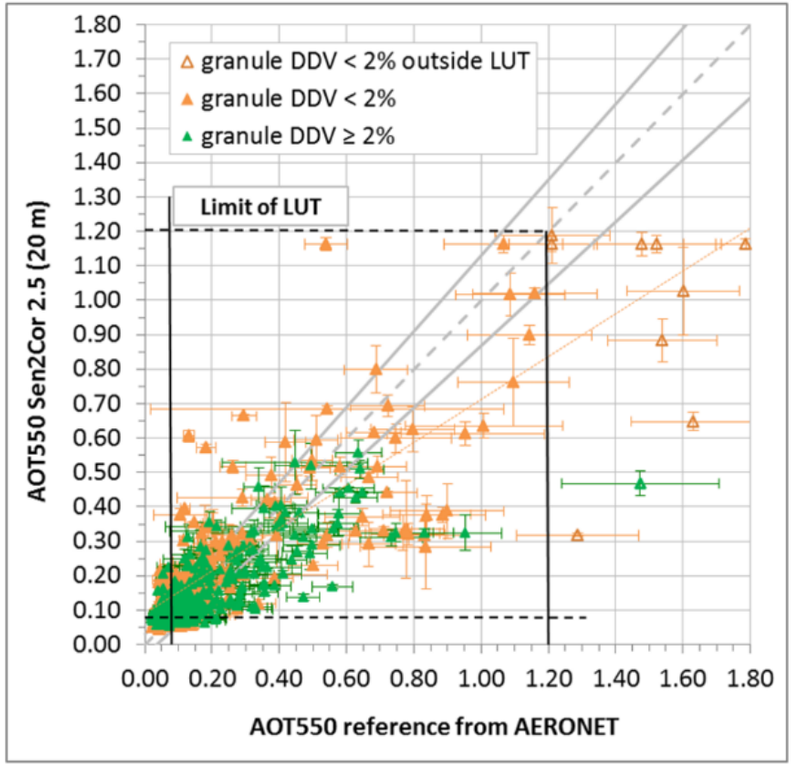
# L2A Validation Results Sen2Cor 2.5 CAMS: AOD product

- Correlation plot of Sen2Cor AOD550 retrieval at 20 m resolution versus AOD550 reference from AERONET (25 AERONET sites).

Sen2Cor 2.5 public version




Sen2Cor 2.5 CAMS prototype




- Using CAMS data as fallback solution in case there are no DDV-pixels in the image show a better distribution of AOD values vs AOD reference values.

# Conclusion and Outlook

- Sentinel-2 Level-2A products (surface reflectance) generated worldwide operationally since December 2018.
- L2A Validation results:
  - AOD retrieval with DDV pixels: about half of the products within requirements

    $|\Delta AOD550| \leq 0.1 * AOD550_{ref} + 0.03$
  - Very accurate Water Vapour retrieval
  - Accurate surface reflectance retrieval for moderate atmospheric conditions
- On-going developments to improve the quality of the cloud screening
- In case DDV pixels are missing in the image a new fallback solution has been developed using meteorological aerosol estimates (CAMS)
- Sen2Cor participates to ACIX-2 and CMIX inter-comparison exercises


YOKOHAMA, JAPAN
13/04/2019
L1C
SENTINEL Hub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SENTINEL 2
Mission Performance Centre

# THANK YOU FOR YOUR ATTENTION!


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Magdalena Main-Knorn

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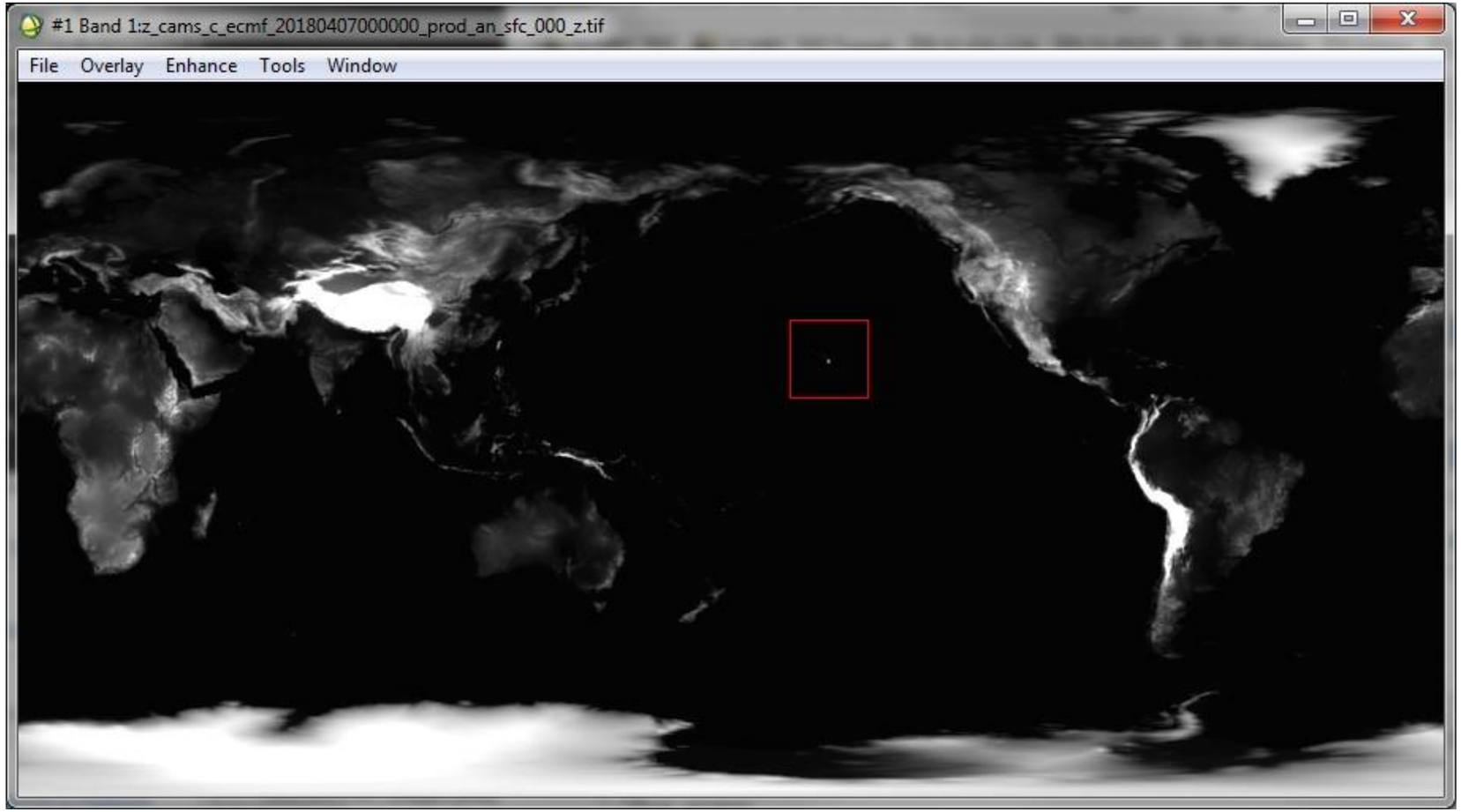
/ 25

# L2A CALIBRATION ACTIVITIES: CAMS-ECMWF AOT




CAMS geopotential used to calculate elevation
elevation = surface geopotential / 9.80665

Resolution 0.4 x 0.4 deg

# L2A PROTOTYPE: MAIN PROCESSING STEPS

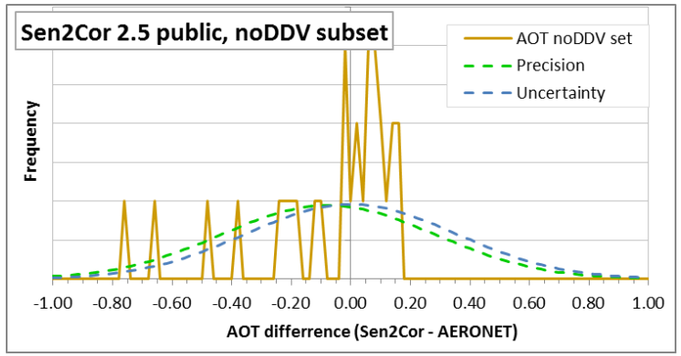
➔ Sen2Cor CAMS prototype now based on 2.8 (public version)

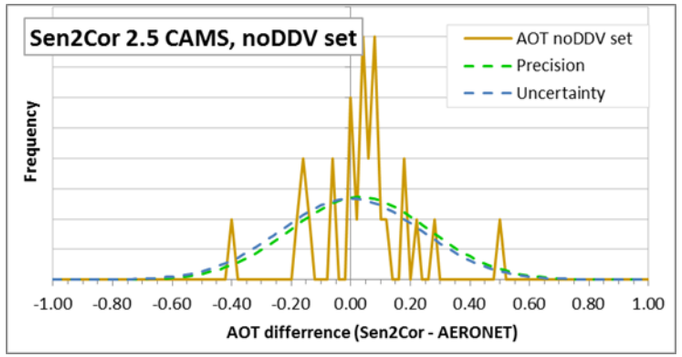
- AOD inputs from CAMS NEAR_REALTIME (FTP) or MACC data from API server
- CAMS AOD data used in AC processing only **when not enough DDV are present**
- CAMS AOD converted to **visibility** (km) using the altitude of the CAMS DEM.
- Visibility spatially and temporally interpolated to S2 geometry and S2 acquisition time.
- Visibility parameter then used in the radiative transfer equations together with Sen2Cor Digital Elevation Model information (PlanetDEM for operational L2A)
- Iterative negative reflectance check performed afterwards:
  If too many negative surface reflectance pixels -> visibility slightly increased (⇔AOD decrease) to reduce the amount of negative reflectance pixels.

# L2A Validation Results Sen2Cor 2.5 CAMS: AOT product

- Sen2Cor 2.5 public in comparison to Sen2Cor 2.5 CAMS; ACIX (water sites excluded)

| AOT statistics | | noDDV set 2.5 public | | noDDV set 2.5 CAMS |
|---|---|---|---|---|
| Total no. of products | | 30 | | 28 |
| Products within requ. | | 27% | | 36% |
| | | | | |
| $R^2$ | (Coefficient of variation) | 0.19 | | 0.60 |
| r | (Pearson's correlation coeff.) | 0.43 | | 0.77 |
| | | | | |
| MA | (Median Accuracy value) | -0.08 | | 0.04 |
| MD | (Median deviation ) | 0.08 | | 0.05 |
| MP | (Median Precision value) | 0.25 | | 0.16 |
| U | (Uncertainty) | 0.25 | | 0.17 |
| | | | | |
| Max $AOT_{550}$ difference | | 0.77 | | 0.48 |
| 95.4% Quantile | | 0.14 | | 0.26 |
| 68.3% Quantile | | 0.07 | | 0.07 |

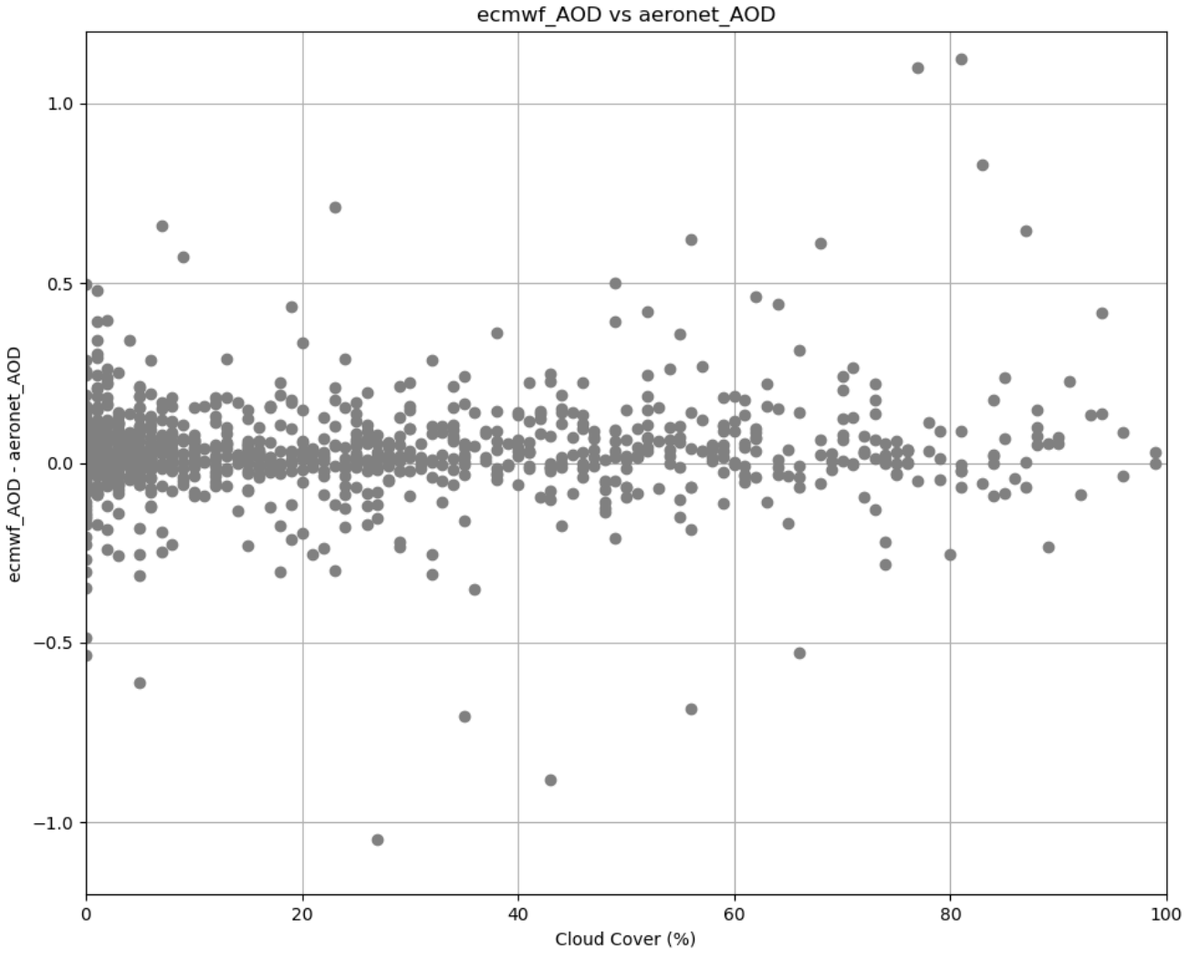



Median Deviation = median ( |Sen2Cor - reference|)

- Much higher correlations, remarkable lower MP, U and Max AOT550 difference, lower A
- More products within requirement

# L2A: ECMWF-CAMS AOD AT 550 NM ASSESSMENT




No direct correlation between cloud coverage and CAMS aod uncertainty

Qualitative analysis of outliers shows that these are often related to a large weather front approaching the aeronet site.

# VALIDATION PROCEDURE

- AOT & WV  validation procedure:
  - direct comparison with AERONET as reference
  - AERONET: satellite overpass time ±30 min
  - Sentinel-2: average over
    - 9km x 9km area around sunphotometer of all vegetated and not-vegetated pixels
- SR validation procedure:
  - Pixel-by-pixel comparison with AERONET corrected (surface reflection) data as reference
  - SR reference computed from [Eric Vermote]
    - Sentinel-2 L1C (TOA) data with
    - 6S radiation transport model using
    - aerosol parameters from AERONET as input
  - AERONET: satellite overpass time ±30 min
  - Sentinel-2:
    - 9km x 9km area around sunphotometer with
    - only non-saturated, non-cloudy and non-missing pixels considered

# VALIDATION PROCEDURE

- Statistical metrics:
  - $X_i = SR_{i,\lambda}, AOT^{550}{}_i; WV_i$ (i:=pixel; λ:= Band)
  - $\Delta X_i = X_{i,\,SEN2COR} - X_{i,\,reference}$
  - Median Accuracy value (median differerence to reference value)

    $$\mathbf{MA} = Median_{i=1}^{n}(\Delta X_i)$$

  - Median absolute Deviation:

    $$\mathbf{MD} = Median_{i=1}^{n}(|\Delta X_i|)$$

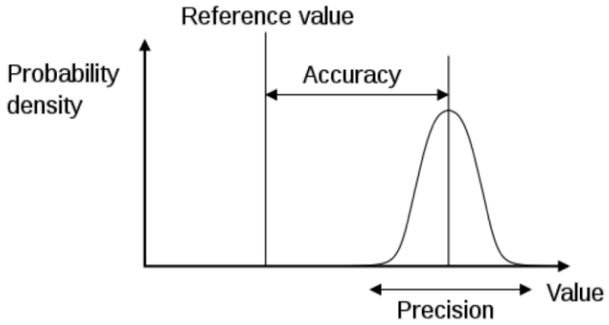
  - Median Precision value (rms around MA)

    $$\mathbf{MP} = \sqrt{\frac{1}{(n-1)} \cdot \sum_{i=1}^{n}(\Delta X_i - MA)^2}$$

  - Uncertainty U (rms around reference value)

    $$\mathbf{U} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\Delta X_i)^2}$$

  - SR per band:
    - MA, MP and U are computed per 0.02-SR-bins and
    - overall values for entire SR range




High accuracy, low precision

high precision, low accuracy